

A Summary of Unmanned Aircraft Accident/Incident Data: Human Factors Implications

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Abstract

A review and analysis of unmanned aircraft (UA) accident data was conducted to identify important human factors issues related to their use. UA accident data were collected from the U.S. Army, Navy, and Air Force. The percentage of involvement of human factors issues varied across aircraft from 21% to 68%. For most of the aircraft systems, electromechanical failure was more of a causal factor than human error. One critical finding from an analysis of the data is that each of the fielded systems is very different, leading to different kinds of accidents and different human factors issues. A second finding is that many of the accidents that have occurred could have been anticipated through an analysis of the user interfaces employed and procedures implemented for their use. The current paper summarizes the various human factors issues related to the accidents.

Introduction

The review and analysis of unmanned aircraft (UA) accident data can assist researchers in identifying important human factors issues related to their use. The most reliable source for UA accident data currently is the military. The military has a relatively long history of UA use and has always been diligent in accurately recording information pertaining to accidents/incidents. The purpose of this research was to review all currently available information on UA accidents and identify human error aspects in those accidents and what human factors issues are most involved.

Two primary sources of accident information were collected from the U.S. Army. The first was a summary of 56 UA accidents produced by the U.S. Army Aeromedical Research Laboratory and obtained from the U.S. Army Risk Management Information System (RMIS). The second was a direct query of the RMIS system of all UA accidents that occurred between January 1986 and June 2004. A total of 74 accidents were identified, the earliest of which occurred on March 2, 1989, and the latest on April 30, 2004.

Information regarding UA accidents for the U.S. Navy was collected from the Naval Safety Center. A summary of 239 UA mishaps occurring between 1986 and 2002 was received from the Naval Safety Center in Pensacola, FL (Kordeen Kor, personal communication).

Air Force accident/mishap information was collected from the Air Force Judge Advocate General's Corps Web site, <http://usaf.aib.law.af.mil/>. A total of 15 Class-A UA mishaps were retrieved from the Web site, covering the dates from December 6, 1999, to December 11, 2003. In addition, a complete accident investigation board report was received.

Classification of the accident data was a two-step process. In the first step, accidents were classified into the categories of human factors, maintenance, aircraft, and unknown. Accidents could be classified into more than one category. In the second step, those accidents classified as human factors-related were classified according to specific human factors issues of alerts/alarms, display design, procedural error, skill-based error, or other. Classification was based on the stated causal factors in the reports, the opinion of safety center personnel, and personal judgment of the author.

Results

There are 5 primary military UA in service currently. The U.S. Army's Hunter and Shadow, the U.S. Navy's Pioneer, and the U. S. Air Force's Predator and Global Hawk. Other systems are being developed and have undergone testing, such as the Mariner system for the U.S. Coast Guard and U.S. Navy but sufficient accident data do not exist to warrant separate analyses of these airframes.

Hunter

The Hunter takes off and lands using an external pilot (EP), standing next to the runway in visual contact with the aircraft, and operating a controller that is very similar to ones used by radio-controlled aircraft hobbyists. After takeoff and climb out, control of the aircraft is transferred to an internal pilot (IP), operating from a ground control station (GCS). The IP controls the Hunter in a more automated fashion, by selecting an altitude, heading, and airspeed for the aircraft using a set of knobs located within the GCS. For landing, control of the aircraft is transferred from the GCS back to an EP. A hook located below the aircraft is used to

snag the aircraft on a set of arresting cables positioned across the runway.

Data from the Hunter program indicated that 15 of the 32 accidents (47%) had one or more human factors issues associated with them. Figure 1 shows the major causal categories for Hunter accidents. Note that the percentages add to more than 100% because some of the accidents were classified into more than one category.

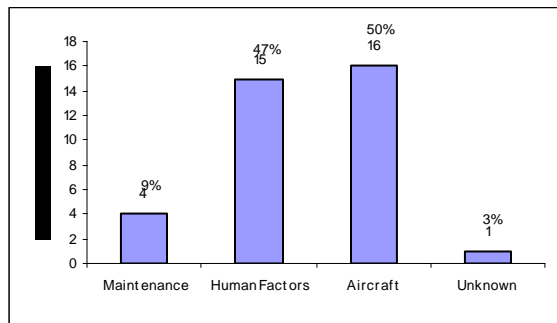


Figure 1. U.S. Army Hunter accident causal factors.

Breaking down the human factors issues further, Table 1 shows how the number and percentage of the 15 human factors-related accidents are associated with specific human factors issues. Again, percentages exceed 100% because of some accidents being classified under more than one issue.

Table 1. Breakdown of human factors issues for Hunter accidents.

Issue	Number	Percent
Pilot-in-command	1	7%
Alerts and Alarms	2	13%
Display Design	1	7%
External Pilot Landing Error	7	47%
External Pilot Takeoff Error	3	20%
Procedural Error	3	20%

By far the largest human factors issue is the difficulty experienced by EPs during landings. Forty-seven percent of the human factors-related Hunter accidents involved an error by the EP during landing. An additional 20% of the accidents involved an error by the EP during takeoff. Control difficulties are at least partially explainable by the fact that when the aircraft is approaching the EP the control inputs to maneuver the aircraft left and right are opposite what they would be when the aircraft is moving away from the EP. This cross-control problem is

present for any UA operated by an external pilot via visual contact.

Besides EP control problems, other issues represented in the table include pilot-in-command issues, alerts and alarms, display design, and crew procedural error. A pilot-in-command issue is a situation where the authority of the controlling pilot is superceded by other personnel in the area, violating the principle that the pilot of the aircraft has the final decision-making authority during a flight. In contrast, alerts and alarms deal with situations where a non-normal flight condition (e.g., high engine temperature) is not conveyed effectively to the crew. Display design issues typically manifest when not all of the information required for safe flight is conveyed effectively to the crew.

Finally, the crew procedural errors referred to here involved three occasions where the crew failed to properly follow established procedures. On one occasion an improper start-up sequence led to data link interference from the backup GCS. On another occasion the crew failed to follow standard departure procedures and the UA impacted a mountain. On a third occasion an EP failed to complete control box checks prior to taking control of the UA and did not verify a box switch that was in the wrong position.

Shadow

Unlike the Hunter, the Shadow does not use an external pilot, depending instead on a launcher for takeoffs, and an automated landing system for recovery. The landing system, called the tactical automated landing system (TALS) controls the aircraft during approach and landing, usually without intervention from the GCS pilot. A cable system, similar to the one used for the Hunter, is used to stop the aircraft after landing. Aircraft control during flight is accomplished by the GCS pilot through a computer menu interface that allows selection of altitude, heading, and airspeed. During landing, GCS personnel have no visual contact with the aircraft, nor do they have any sensor input from onboard sensors. A command to stop the aircraft engine is given by the GCS pilot, who must rely on an external observer to communicate that the plane has touched down.

The analysis of Shadow accidents shows a different pattern from that seen with the Hunter. In contrast to the Hunter, only 5 of the 24 Shadow accidents (21%) were attributed to human factors issues. Figure 2 shows the major causal factors for the Shadow accidents.

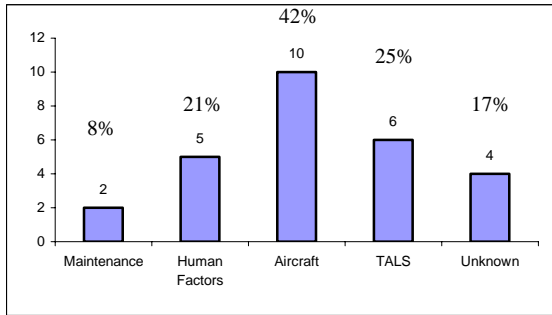


Figure 2. U.S. Army Shadow accident causal factors.

In addition to the four categories used for the Hunter accidents, an additional category was added for Shadow to include failures of the tactical automated landing system (TALS). While eliminating landing accidents potentially attributable to an EP, the use of TALS is not perfect, as shown from the data. Use of the launcher eliminated any EP takeoff errors for these aircraft.

Breaking down the human factors-related accidents, Table 2 shows the number and percentage of the 5 accidents related to specific human factors issues. As can be seen from the table, the distribution of issues is evenly divided across pilot-in-command, alerts and alarms, display design, and procedural errors.

Table 2. Breakdown of human factors issues for Shadow accidents.

Issue	Number	Percent
Pilot-in-command	2	40%
Alerts & Alarms	2	40%
Display Design	2	40%
Procedural error	2	40%

For both the Hunter and Shadow, at least one accident involved the transfer of control of the aircraft from one GCS to another during flight, an activity unique to UA. In the case of the Shadow, two aircraft were damaged during a single mission. The first was damaged due to a TALS failure. After the accident, the GCS crew issued a command to the damaged aircraft to kill its engine, but because of damage to the antenna the command was not received. That same GCS was then tasked with controlling a second Shadow that was on an approach. Unfortunately, after taking control of the second Shadow, the aircraft received the “engine kill” command that was still waiting for an acknowledgment from

the GCS software, causing the second Shadow to crash also. This accident was classified as both a procedural error, because the crew failed to follow all checklist items prior to the transfer of control of the second aircraft, and a display design problem, because there was not a clear indication to the crew of the status of the “engine kill” command that had been issued.

Pioneer

Like the U.S. Army’s Hunter UA, the Pioneer requires an EP for takeoff and landing. After takeoff, the aircraft can be controlled from a GCS in one of three modes. In the first mode the air vehicle is operated autonomously and the autopilot uses global positioning system (GPS) preprogrammed coordinates to fly the air vehicle to each waypoint. In the second mode, the IP commands the autopilot by setting knobs (rotary position switches) to command airspeed, altitude, compass heading or roll angle, and the autopilot flies the UA. In the third mode, the IP flies the aircraft using a joystick. The Pioneer can be landed at a runway using arresting cables, but because it is a U.S. Navy/Marine operated aircraft, it is also landed on board a ship by flying into a net. There are plans for implementing an automated landing system for the Pioneer for ship-based landings.

A list of 239 Pioneer accidents was received from the Navy Safety Center. Although not providing much detail, the data did allow a general categorization of accidents into principle causal categories. Figure 3 shows the major causal factors for Pioneer accidents.

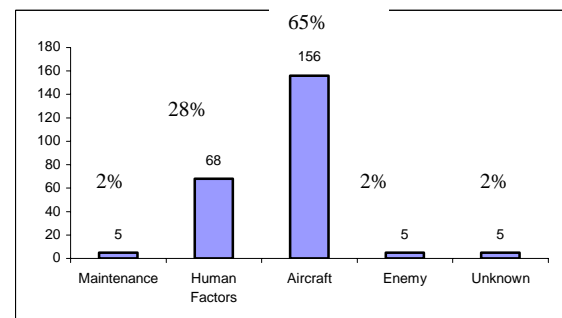


Figure 3. U.S. Navy Pioneer UA accident causal factors.

As can be seen from the figure, human factors-related issues were present in approximately 28% of the accidents. Breaking down the human factors-related accidents further, Table 3 lists the number and percentage of the 68 accidents related to specific human factors issues.

Table 3. Breakdown of human factors issues for Pioneer accidents.

Issue	Number	Percentage
Aircrew Coordination	9	13%
Landing Error	46	68%
Take-off Error	7	10%
Weather	6	9%

As with the U.S. Army Hunter accidents, the largest percentage of human factors accidents (68%) was associated with the difficulty experienced by the EP while landing the aircraft. An additional 10% of the accidents were associated with takeoffs, although the primary means of taking off is through the use of a launcher (from ship-based aircraft). In addition to landing and takeoff errors, two other issues seen with the Pioneer were aircrew coordination, which includes procedural and communication type errors, and weather-related accidents, which deal with pilot decision-making. Unfortunately, details regarding these accidents were not sufficient to identify issues beyond this level.

Predator

The Predator made its first flight in June 1994. There are two Predator types, currently designated as MQ-1 and MQ-9, also called Predator and Predator B. The Predator aircraft is flown from within the GCS, similarly to a manned aircraft, using a joystick and rudder pedals and a forward-looking camera that provides the pilot with a 30-degree field of view. The camera is used for both takeoffs and landings.

The Predator accident causal factors are shown in Figure 4. As can be seen from the figure, human factors encompass a higher percentage (67%) than aircraft-related causes, unlike the other aircraft examined thus far.

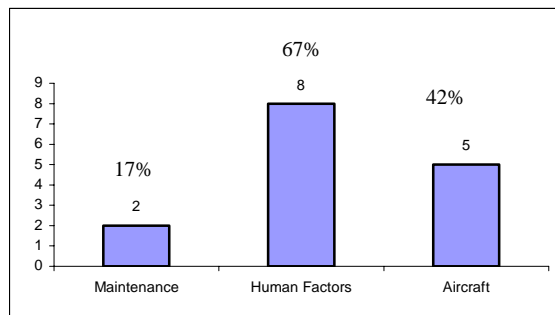


Figure 4. Air Force Predator accident causal factors.

Table 4 shows a breakdown of the human factors issues associated with Predator accidents. The majority of human factors-related problems were concerned with procedural errors on the part of the flight crew. One of these accidents involved yet another problem with a handoff of the aircraft from one GCS to another. During the handoff, the mishap crew did not accomplish all of the checklist steps in the proper order, resulting in turning off both the engine and the stability augmentation system of the aircraft. The aircraft immediately entered an uncommanded dive and crashed.

Table 4. Breakdown of human factors issues for Predator accidents.

Issue	Number	Percentage
Alerts & Alarms	1	13%
Display Design	2	25%
Landing Error	1	13%
Procedural Error	6	75%

A second procedural error of note occurred when the pilot accidentally activated a program that erased the internal random access memory on board the aircraft during a flight. That this was even possible to do during a flight is notable in itself and suggests the relatively ad hoc software development process occurring for these systems (Tvaryanas, 2004).

Global Hawk

The Global Hawk, made by Northrop Grumman, is the largest and newest of the 5 military systems discussed. The first flight of the Global Hawk occurred in February 1998, and it became the first UA to cross the Pacific Ocean in April 2001 when it flew from the United States to Australia (Schaefer, 2003).

The Global Hawk is the most automated of all the systems discussed. All portions of the flight, including landing and takeoff are pre-programmed before the flight and the basic task of the crew during the flight is simply to monitor the status of the aircraft and control the payload. While this makes flying the Global Hawk very simple, the mission planning process is unwieldy and requires a great deal of time to accomplish.

Only three accident reports were available for the Global Hawk. Of these three reports, one did not provide sufficient information for classification, a second faulted a failure in a fuel nozzle, which led to an engine failure, and the

third was a human factors issue centering on the complicated mission planning process. In that accident, the mishap aircraft suffered an inflight problem with temperature regulation of the avionics compartment and landed at a preprogrammed alternate airport for servicing. After landing, the aircraft was commanded to begin taxiing. Unknown to the crew, a taxi speed of 155 knots had been input into the mission plan at that particular waypoint as a result of a software bug in the automated mission planning software in use at the time. The aircraft accelerated to the point it was unable to negotiate a turn and ran off of the runway, collapsing the nose gear and causing extensive damage to the aircraft.

Conclusions

One conclusion apparent from the data reported here is that, for most of the systems examined, electrical and mechanical reliability play as much or more of a role in the accidents as human error. Mishaps attributed at least partially to aircraft failures range from 33% (Global Hawk) to 67% (Shadow) in the data reported here.

An improvement in electromechanical reliability will probably come only through an increase in the cost of the aircraft. However, a reduction of human errors leading to accidents might not necessarily entail increased costs if suggested changes can be incorporated early in the design process. In the systems analyzed, human factors issues were present in 21% (Shadow) to 67% (Predator) of the accidents. These numbers suggest there is room for improvement if specific human factors issues can be identified and addressed.

In that regard, it is important to note that many of the human factors issues identified are very much dependent on the particular systems being flown. For example, both the Pioneer and Hunter systems have problems associated with the difficulty external pilots have in controlling the aircraft. For both of these systems, the majority of accidents due to human error can be attributed to this problem. However, the other three systems discussed do not use an EP and either use an IP (Predator) or perform landings using an automated system (Shadow and Global Hawk).

The design of the user interfaces of these systems are, for the most part, not based on previously established aviation display concepts.

Part of the cause for this is that the developers of these system interfaces are not primarily aircraft manufacturers. Another reason is that these aircraft are not “flown” in the traditional sense of the word. Only one of the aircraft reviewed (Predator) has a pilot/operator interface that could be considered similar to a manned aircraft. For the other UA, control of the aircraft by the GCS pilot/operator is accomplished indirectly through the use of menu selections, dedicated knobs, or preprogrammed routes. These aircraft are not flown but “commanded.” This is a paradigm shift that must be understood if appropriate decisions are to be made regarding pilot/operator qualifications, display requirements, and critical human factors issues to be addressed.

If the aircraft is commanded to begin taxiing, there should be information available regarding the intended taxi speed. If the aircraft is being handed off from one station to another, the receiving station personnel should be aware of what commands will be transmitted to the aircraft after control is established. Interface development needs to be focused around the task of the pilot/operator. For most of these aircraft, that task is one of issuing commands and verifying that those commands are accepted and followed. Understanding this task and creating the interface to support it should help to improve the usability of the interface and reduce the number of accidents for these aircraft. This is especially important as these aircraft begin to transition to the National Airspace System (NAS), conducting civilian operations in among civilian manned aircraft.

References

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